

Istituto Nazionale di Fisica Nucleare



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D mesons and charmed baryon production in small systems with ALICE

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Why open heavy flavours in small systems in ALICE?

- Charm and beauty give a unique probe of the QGP formed in ultrarelativistic heavy-ion collisions
- Produced at early times in hard partonic scatterings (high-Q²)
 - → $m_{c,b} \gg \Lambda_{QCD}$ → cross section calculable within perturbative QCD framework
 - → D_s meson and Λ_c baryon allow tests of hadronisation effects due to possible quark recombination
- Small systems serve as vital baselines for HI measurements:
 - → pp collisions: Measure production cross sections, baseline for nuclear collisions, test for pQCD calculations.
 - → **p-Pb collisions**: Study cold nuclear matter effects to distinguish initial-state nuclear modifications from final-state in-medium effects
 - → Search for possible collective-like effects at high multiplicity







ALICE: A Large Ion Collider Experiment



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D-meson ratios in pp collisions



- Particle ratios: test universality of D-meson fragmentation in pp collisions
- Ratios do not significantly differ as function of $p_{\rm T}$ or collision energy
- Holds true also for strange D mesons: No change of fragmentation from strangeness contribution within measured region



Eur.Phys.J. C79 (2019) no.5, 388

Measurement of non-prompt D⁰ in pp collisions

ALICE

- Indirect measurement of b-hadron production using D mesons from beauty decays
- New measurement with machine learning techniques to extract signal
- Allows data-driven approach to f_{prompt} calculation, test of beauty production in pQCD calculations
- Comparison with FONLL: data consistent with theory but populates upper region of uncertainty band



FONLL: JHEP 10 (2012) 137

D-meson production in p-Pb collisions

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arXiv:1906.03425 [nucl-ex]



• Nuclear modification, R_{pPb} : Normalised production crosssection, rescaled by pp reference

- Consistent with unity: no significant modification in p-Pb collisions, described well by models of Cold Nuclear Matter effects
- *Q*_{pPb}: no significant centrality dependence; consistent also with light-flavour charged particles

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Charmed baryon production



- Vital tool to test charm fragmentation: baryon-tomeson ratio sensitive to hadronisation mechanisms
- Light-flavour sector: enhancement of Λ/K⁰ production ratio in Pb–Pb collisions compared to pp; possible effect of quark recombination inmedium? Is this effect present in the charm sector?
- Previous STAR measurement: enhancement of Λ_c⁺/D⁰ ratio in Au–Au collisions compared with expectations from models
 - → Is this effect seen at the LHC?
 - → Implications for understanding of charm hadronisation?



STAR Preliminary: arXiv:1704.04353

Λ_c nuclear modification factor



- Λ_c measured in two decay channels: pK_s^0 and $pK^-\pi^+$; averaged to give final result
- R_{pPb} of Λ_c : Consistent with unity within uncertainties; also consistent with D-mesons at all p_T
- Described by models including only CNM effects (POWHEG+PYTHIA6) and those including formation of small QGP (POWLANG)

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Charmed baryon-to-meson ratio





- Run-2 measurements in pp, p-Pb and Pb-Pb collisions (from 2018 sample)
- pp and p-Pb collisions in good agreement
- Hint of increase of baryon-to-meson ratio in central Pb-Pb collisions at intermediate $p_{\rm T}$

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- Comparison with light flavours: Results show very similar trend to strangeness sector (Λ/K⁰_s)

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- Baryon-to-meson ratio better described by models including enhanced colour reconnection mechanisms

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Higher charmed baryon states: Ξ_c^{0}



- Ξ_c^{0} baryon: strange charmed baryon. Examine role of strangeness in baryon production
- First measurement of Ξ_c^{0} baryon at LHC^[1] in proton-proton collisions via semileptonic decay
- Above: cross section x BR in five p_T intervals (absolute branching fraction still unknown^[2])
- Below: Ξ_c⁰/D⁰ production ratio underpredicted by PYTHIA MC model^[3]
 - → Charm baryon hadronisation still to be better understood in hadronic collisions

[1] ALICE Collaboration, Phys.Lett. B781 (2018) 8-19
[2] Particle Data Group, Chin. Phys. C, 40, 100001 (2017)
[3] P. Skands et al., Eur. Phys. J. C74 (2014) 3024



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Conclusions / outlook



- pp and p-Pb collisions: More than just a baseline!
 - → More precise measurements of D-meson production give test of pQCD calculations down to ultralow $p_{\rm T}$
 - → Non-prompt D⁰ measurement gives indirect access to beauty sector
 - → Charmed baryon production generally underestimated by models, but better described with enhanced colour reconnection mechanisms
- Analyses on full Run-2 pp sample at 13 TeV ongoing, large data set offers more precise measurement
- Prospects for measurements of Ξ_c^{0} , Ξ_c^{+} , Σ_c baryon production in hadronic decay channels
- Run-3 and beyond: Possibility to reconstruct beauty hadrons in hadronic decays using upgraded ITS + TPC



Reconstruction of heavy-flavour hadrons

- Open heavy-flavour hadrons reconstructed in ALICE primarily through semileptonic and fully hadronic decay channels
- Particle identification (PID) using TPC and TOF for signal selection
- Fully hadronic decays: e.g. $D^0 \rightarrow K^- \pi^+$, $D_{s^+} \rightarrow \phi \pi^+$, $\Lambda_c^+ \rightarrow p K_s^0 / p K^- \pi^+$ (and c.c.)
 - → No missing mass → captures full kinematic information of mother particle; better access to transport coefficients in medium
 - → Topological selections and PID to suppress background
- Semileptonic decays: c/b/ $\Lambda_c^+/\Xi_c^0 \rightarrow e^{\pm} \nu_e + X$
 - → Alternative approach with large branching ratio for analysis where vertexing more difficult, e.g. Ξ_c^0





D-meson production cross sections in pp collisions





- D⁰ measured down to ultra-low p_T by relaxing topological selections: possible to directly extract total cross-section
- Differential cross-section described by pQCD calculations:
 - → FONLL: Generally within uncertainties, with data populating upper uncertainty band
 - → GM-VFNS: Generally good agreement within uncertainties
 - → $k_{\rm T}$ factorisation: tends to overestimate at high $p_{\rm T}$

[1]: Eur. Phys. J. C77 (2017) 550; [2]: Eur.Phys.J. C79 (2019) no.5, 388 FONLL: JHEP 10 (2012) 137 GM-VFNS: Eur. Phys. J. C72 (2012) 2082; JHEP05 (2018) 196 *k*_γ factorisation: PRD 87 (2013) 094022



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Multiplicity dependence in small systems



 "Self-normalised yield": Examine correlation between heavy-flavour production & overall charged-particle production in pp and p-Pb collisions



- Faster-than-linear increase seen for D mesons and beauty hadrons. Implies increase of HF production in multi-parton interactions
- Results described well by hydrodynamic models

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Λ_c production cross-section in pp and p–Pb collisions





- Λ_c measured in two decay channels: pK_s^0 and $pK^-\pi^+$
- Run-2 data brings greatly improved statistics over Run-1; smaller stat. uncertainties and better $p_{\rm T}$ reach available
- Measurements consistent between decay channels; are averaged to give overall Λ_c cross-section EPS-HEP 2019 J. Wilkinson